DETAIL DESIGN DESCRIPTION

CHAPTER 12
TAILRACE SYSTEM

[UPPER TRISHULI-1 HEP (216MW)]

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DOOSAN Enerbility

FOR INFORMATION

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12 Tailrace Tunnel & outlet

12.1 General

12.1.1 Layout of tailrace system

The whole tailrace system is composed of four parts, which are three draft tunnels connecting with draft tube, bifurcation tunnel and downstream surge chamber, tailrace tunnel and outlet. Three draft tunnel collect the water flow through the turbine to the bifurcation tunnel, and through the tailrace tunnel will be transported to the outlet, and then the outlet will be smoothly transported to the downstream.

In the process of selecting the most economical and hydraulically favorable alignment of the headrace tunnel, firstly, the shortest path between the power house and the outlet is considered, taking into account its function, topographical and geological conditions, constructability and the locations of other structures associated with the powerhouse. The alignment has been planned to be a straight line as much as possible.

Considering underground powerhouse and entire route, draft tunnel is planned parallelly to route of tailrace tunnel. In order to proceed maintenance works in draft tube, slide gate installation is planned at the end of draft tunnel. The draft tunnel has a rectangular section with a section size of 3.5m × 3.5m after lining, and the horizontal length of single draft tunnel is 38.95m.

The surge chamber is integrated with the bifurcation tunnel. The purpose of the bifurcation tunnel is to gather the water flow through the three draft tunnel together, turn the three-way water flow into a unidirectional flow, and transport it to the tailrace tunnel. The downstream surge chamber is arranged on the top of bifurcation tunnel, and connected with the lower bifurcated tunnel through three throttles. The horizontal length is 16.30m.

The tailrace tunnel is under relatively low pressure and the outlet need to safely release the plant discharge to the downstream river. The tailrace tunnel is connecting the bifurcation tunnel and outlet. The horizontal length of the tailrace tunnel is 229.422m, the section shape after lining is circle, and the section size is 6.5m.

The outlet is arranged on the right bank of Mailun River, where excavation is less and the portal installation is proper. The bottom elevation of the tailrace outlet is determined as EL. 910 m which is about 20 years frequency flood water level, and the top platform elevation is EL.927m. A bulkhead gate is installed at the outlet.

In the early stage, one is about 150m long, the section is D-shaped, and the size is 2m × 2m test tunnel has been excavated, and the geological data near the underground powerhouse is revealed. Due to the impact of the 2015 earthquake, the topography of the tailrace outlet changed greatly.

The tunnel crosses mainly rock types of schist unit (quartzitic schist & mica schist). In general, the rock quality along the tunnel is considered to be medium strong to very strong in strength. The rocks on surface are slightly to moderately weathered. It is expected that gneiss unit is stronger than schist unit in strength. Bedrock is exposed mainly in the small creeks and in the form of steep cliff at higher elevation along the tunnel routes.

The layout of tailrace system refer to LAYOUT DRAWING OF TAILRACE SYSTEM (UT1-C-070-CVL-DG-59001), the latest revision.

12.1.2 Design Criteria

The purpose of the tail tunnel is to carry the water flowing through the power house smoothly and safely downstream.

A. The tailrace tunnel is a concrete lined tunnel of 6. 5 m internal diameter and shotcrete lined modified horse shoe tunnel of inner dia. 7. 0m.

B. The alignment of the tailrace tunnel is chosen to ensure that adequate cover to the crown is maintained throughout the length of the tailrace tunnel.

C. The tailrace tunnel shall be designed to safely withstand extremes of internal and external pressure at all points.

D. The maximum flow velocity in concrete lined tailrace tunnel sections shall be less than 3. 0m/s.

E. Tunnel support measures shall be provided to ensure stability of the tailrace tunnel and surrounding rock mass. Permanent rock support measures shall be determined on the basis of physical rock parameters at unlined section.

F. Subject to compliance to design requirements commensurate with rock quality the Contractor may propose sections of the tailrace tunnel with either a concrete or shotcrete lining for the permanent support with the condition that there will be no loss of water from the tunnel.

G. Notwithstanding (H) above, concrete with at least a 30cm thickness shall be placed at the invert of the concrete lined tailrace tunnel. The arch or side wall of the tailrace tunnel shall be covered with shotcrete with wire netting/fibre shotcrete or concrete Wire netting shall be spread between primary shotcrete and secondary shotcrete. The final thickness of the shotcrete or the concrete along the arch or side wall of the tailrace tunnel shall be as indicated on the Employer's concept Drawings for construction of the Works and as determined by the rock quality class.

H. Any cracks, cave ins and overbreaks inside the lined section of tailrace tunnel shall be adequately filled by concrete or any other suitable materials in order to avoid any water leakage from the tunnel.

I. The internal and external water pressure generated during operation period shall be considered separately from safety measures required during the construction period.

J. Consolidation grouting shall be carried out in accordance with the drawings to enhance the integrity of the rock behind the lining.

K. The specifications are subject to change depending upon the detailed design results.

12.1.3 Reference

Contract Documents, Annex 13 Employer's Requirement

Value Engineering Report (hereafter called "VE report"), dated December 2019

PowerChina's Optimization Engineering Report

Design Optimization Proposal -Technical Meeting Notes LTA visit #1 (May 2022)

Tunnels and Chambers in Rock (EM 1110-2-2901)

Strength Design for Reinforced Concrete Hydraulic Structures (EM 1110-2-2104)

Waterstops and Other Preformed Joint Materials for Civil Works Structures (EM 1110-2-2102)

Civil Engineering Guidelines for Planning and Designing Hydroelectric Developments-Waterways (ASCE Vol 2)

High Strength Deformed Steel Bars and Wires for Concrete Reinforcement Specification (Fourth Revision) (IS 17126-20012)

12.2 Geology

12.2.1 Rock Type

The major rock types in the tailrace tunnel alignment are of quartzitic schist, mica schist.

12.2.2 Rock Quality of tunnel

The tunnel crosses mainly two rock types of schist unit (quartzitic schist & mica schist). In general, the rock quality along the tunnel is considered to be medium strong to very strong in strength. The rocks on surface are slightly to moderately weathered. It is expected that gneiss unit is stronger than schist unit in strength. Bedrock is exposed mainly in the small creeks and in the form of steep cliff at higher elevation along the tunnel routes.

The site consists of alluvium and bedrock. The depth of bedrock is encountered at 13. 3 m depth from ground. The talus deposits in the tailrace tunnel area consist mainly of angular rock fragments, and rock blocks. The boulders and gravels mixed in gravely matrix in the deposits are originated from gneiss, schist and quartzite. Discontinuity data statistically analyzed indicates three major sets of joint including foliation.

The tunnel alignment is almost nearly parallel to the strike of the foliation having 20°~30°dip, which will give a fair tunneling condition for excavation. The RMR and Q values in this area range 56~73 and 34. 2 respectively, indicating the rock mass class of III.

12.3 Rock Quality of outlet

The tailrace outlet is located at the right bank in Trishuli River. In this area, the drilling investigation for one hole, the water pressure test(6 times),and surface geological survey were performed, and then general analysis of investigation results was performed. As a result of analysis on bedrock distribution, the colluviums belong to schist unit(mica schist+quartzitic schist),and appeared at the depth of less than G.L(-)13.3m.The colluvial deposits composed of sand, silt,gravel and boulder originated from bedrocks are distributed in unconformity on the upper part of bedrocks.

The bedrock consists dominant of green-grey quartzitic schist interpolated with thin bands of grey mica schist with quartz veins to depth of 46.00m.The material in between 46.00 to 49.80m consists of mica schist dominantly. The bedrock is grey, fresh to slightly weathered, strong to medium strong, slightly fractured to highly fractured and thinly to thickly foliate. The orientation of joints through core axis(TCA)varies from 20°to 60°with planar rough to planar smooth and undulated smooth joint roughness. The core recovery in bedrock ranges from 20 to 100%(avg.88%)and the RQD ranges from 0 to 100%(avg.55%).

12.4 Draft tunnel

Draft tunnel is located between main powerhouse cavern and bifurcation tunnel, with three axes, perpendicular to the vertical axis of the powerhouse and arranged in parallel, each of which is 38.95m in length. The axis is arranged horizontally with an elevation of EL.901.95m. A transition section is provided at the beginning.

12.4.1 Cross section

According to the contract design, the excavation section shape of the draft tunnel is D-type, the section after lining is square, and the dimension after lining is 3.5m.

12.4.2 Rock Support

Initial and final rock support and reinforcement systems are designed based on the geologic conditions encountered. Consideration shall be given to the long-term performance of the rock support and reinforcement systems if they are integral to the structural performance of the tunnel lining systems.

Permanent rock support and reinforcement are designed in accordance with USACE EM-1110-2-2901, and ASCE Vol 2-Civil Engineering Guidelines for Planning and Designing Hydroelectric Developments-Waterways.

Rock support shall be designed to carry all ground loads such that no ground loads are transferred to the final linings, unless there are situations where linings are specifically designed for such conditions.

The surrounding rock is mainly classified as Class II to Class IV as per investigation results of test tunnel, proposed systematic initial and final support measures intend to be adopted are summarized in table 12. 6-1.

Table 12-7-4 Proposed initial support of tailrace tunnel

Rock class	Initial support
II	(1) plastic fiber shotcrete: 0. 05m (2) grouted rock dowel: L=2.5m, spot, dia. 25mm
III	(1) plastic fiber shotcrete: 0. 08m (2) grouted rock dowel: L=2.5m@2. 0m×2. 0m staggered, dia. 25mm
IV	(1) plastic fiber shotcrete: 0. 1m(without steel support), 0. 16m(with steel spport) (2) grouted rock dowel:L=2.5m@1. 5m×1. 5m staggered, dia. 25mm (3) steel support: MB150@0. 12m (where necessary)
Remark	(1) The cylinder specified compressive strength of shotcrete and cement mortar at 28 days of age is 25MPa. (2) The yield strength of steel is 250MPa.

Considering complexity of the geological conditions of underground tunnel, the above supporting measures intended to be adopted/applied shall be subject to adjustment when tunnel is exposed.

The excavation and support of tailrace tunnel, please refer to Excavation and Support Drawing of Tailrace Tunnel (UT1-C-070-CVL-DG-59002) and Stability Calculations for the Surrounding Rock of Tailrace Tunnel (UT1-C-070-CVL-DC-59001).

12.4.3 Lining Design

The draft tunnel is lined with reinforced concrete with compressive strength of 24MPa. The lining thickness of side wall and invert slab is 0.5mm, the Max. thickness of top slab is 1.2m, and the shape after lining is square with side length is 3.5m.

12.5 Bifurcation tunnel and surge chamber

12.5.1 Basic layout

Based on the CFD calculation of the tailrace system, the scheme of surge chamber and three bifurcation tunnel in the bidding document was modified. The modification incorporated combining of three small surge chambers to a single surge chamber to increase its volume. Bifurcation tunnel is arranged under the surge chamber and are communicated through throttle. The gate shaft and throttle are arranged in combination, and the gate lifting equipment is arranged in the main transformer cavern.

The upstream of bifurcation tunnel is the extension part of three draft tunnels with the rectangular section. Each end of draft tunnel is arranged with a flat gate, and the gate opening size is 3.5m×3.5m. The axis of the middle tunnel overlaps with the axis of the tailrace tunnel, and the axis of the two sides of the tunnel meets the middle tunnel after turning 90 degrees. The downstream arranges the exit tunnel of the bifurcation tunnel, which is connected with the tailrace tunnel. The two sides of the exit tunnel are arc shaped, and A gradient curve is used at the top. The section size in the exit tunnel is 6.5m×6.5m. The maximum width of the bifurcation tunnel plane is 4.75m and the maximum length is 35.5m.

The horizontal section of the upper surge chamber is basically similar to that of the lower bifurcation tunnel. The maximum width and length of the horizontal section are 3.75m and 35.5m respectively.

According to the CFD calculation of the tailrace system, the highest surge wave in the surge chamber is EL.916m. If the safety height is 1.5m, the minimum height of the top side wall of the surge chamber is EL 917.5m. The hole size of the throttle of the surge chamber is 3.5m×1.25m.

A movable crane is arranged at the top of the surge chamber located in the main transformer cavern, which can meet the lifting demand of the gate during power generation. The layout will be explained in detail in the main transformer cavern.

Detailed design is shown in LAYOUT DRAWING OF TAILRACE SYSTEM (UT1-C-070-CVL-DG-59001).

12.5.2 Lining design

The full section of bifurcation tunnel and surge chamber is lined by reinforcement concrete. The Min. thickness of lining concrete for bifurcation tunnel is 1m, and The Min. thickness of lining concrete for surge chamber is 0.8m.

12.5.3 Support design

The bifurcation tunnel and surge chamber are initially supported by rock dowel and plastic fiber shotcrete. The diameter of dowel is 25mm, the spacing between rows is 2.5m, the length is 3m. The thickness of plastic fiber shotcrete is 0.1m. the steel Support will be used if required.

12.6 Tailrace tunnel

Tailrace tunnel is planned parallelly to route of draft tunnel. The tailrace tunnel is divided into three parts: first part the slope ratio for the vertical alignment is set as 1. 80%， with center elevations of inlet and end are El. 901.95 m and El. 905.684 m respectively, the horizontal length is 207. 422 m; second part the slope ratio for the vertical alignment is set as 37. 83%, with center elevations of inlet and end are El. 905.684m and El. 913.25m respectively， the horizontal length is 20m; third part is a horizontal alignment with centerline elevation of EL.913.50m and the horizontal length is 2m. The transition is arranged between the three parts, The transition section adopts an arc curve with a radius of 6.5m.

12.6.1 Cross section

According to the contract design, the excavation section of the tailrace tunnel is horseshoe shape, the section after lining is circular, and the diameter after lining is 6.5 m.

The flow velocity v=Q/S=76 m3/s / 33. 112m2=2. 29 m/s＜3. 0m/s, which meets the requirement of contract specification.

12.6.2 Drainage

Weep holes are intended to be applied to the concrete lining to reduce external water pressure when tunnel is emptied for inspection or maintenance in combination of consolidation grouting.

The recommended weep hole is 50mm in diameter and 0.3m into rock.

12.6.3 Rock Support

Initial and final rock support and reinforcement systems are designed based on the geologic conditions encountered. Consideration shall be given to the long-term performance of the rock support and reinforcement systems if they are integral to the structural performance of the tunnel lining systems.

Permanent rock support and reinforcement are designed in accordance with USACE EM-1110-2-2901, and ASCE Vol 2-Civil Engineering Guidelines for Planning and Designing Hydroelectric Developments-Waterways.

Rock support shall be designed to carry all ground loads such that no ground loads are transferred to the final linings, unless there are situations where linings are specifically designed for such conditions.

The surrounding rock is mainly classified as Class II to Class IV as per investigation results of test tunnel, proposed systematic initial and final support measures intend to be adopted are summarized in table 12. 6-1.

Table 12-7-4 Proposed initial support of tailrace tunnel

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III	(1) plastic fiber shotcrete: 0. 08m (without test tunnel), 0.1m (with test tunnel) (2) grouted rock dowel: @2. 0m×2. 0m, dia. 25mm, staggered, L=3m(without test tunnel), L=4m (with test tunnel)
IV	(1) plastic fiber shotcrete: 0.1m(without steel support),0.16m(with steel spport) (2) grouted rock dowel:L=3m@1. 5m×1. 5m staggered, dia. 25mm (3) steel support: MB150@0. 12m (where necessary) (4) invert concrete, 0. 2m thick
Remark	(1) The cylinder specified compressive strength of shotcrete and cement mortar at 28 days of age is 25MPa. (2) The yield strength of steel is 250MPa.

Considering complexity of the geological conditions of underground tunnel, the above supporting measures intended to be adopted/applied shall be subject to adjustment when tunnel is exposed.

The excavation and support of tailrace tunnel, please refer to Excavation and Support Drawing of Tailrace Tunnel (UT1-C-070-CVL-DG-59002), Stability Calculations for the Surrounding Rock of Tailrace Tunnel (UT1-C-070-CVL-DC-59001), the latest revision.

12.6.4 Lining Design

The tailrace tunnel is lined with reinforced concrete with compressive strength of 24MPa. The lining thickness is 0.4m, and the shape after lining is circle shape with inner diameter of 6. 5m.

12.7 Tailrace outlet

The direction of the tailrace outlet should be parallel to the downstream river as much as possible in order to safely release the plant discharge without opposite bank damage.To avoid high flood risk caused by the narrow downstream river during construction, the outlet elevation is set above the flood water level, rather than submerged in the downstream river.To against erosion damage caused by high velocity in front of the outlet , some protection works are performed.

12.7.1 Water level

The plant discharge under pressure flow in the tailrace tunnel becomes open flow due to lowered water level caused by head loss in the tailrace tunnel as it flows to the outlet. For the estimation of energy generation, the lowered water level should be applied.

The plant discharge from the tailrace outlet flows into Trishuli River in an angle of approximately 33°to minimize turbulence and damage on the opposite bank.

It is expected that the tailrace outlet will not be affected by sedimentation problem because of its location is relatively higher elevation than the downstream water level.

The final bottom elevation of the tailrace outlet is determined as EL. 910 m which is about 20 years frequency flood water level.

12.7.2 Basic layout

The current location of tailrace outlet makes full use of the space between the river and the right bank slope. On the one hand, it does not affect the normal flow of the river, on the other hand, it reduces the excavation and avoids the damage to the road on right bank.

The tailrace outlet is composed of four parts: gradient section, gate chamber section, tail culvert section and tailrace channel.

The gradient section is 10m in length, from circle (diameter 65m) to square (section size 6.5m×6.5m).

The length of gate chamber is 5.8m. A gate is installed for maintenance of the tailrace tunnel during monsoon season (Over 10yrs frequency flood). The size of the gate is W6. 5m X H6. 5m. The height of the bottom plate of outlet is EL.910.00m, and the top platform is EL.927.000m. A gate lifting frame was built on the platform.

The length of tailrace culvert is 8m, and rectangular section with dimension of 6.5m×6.5m.

The tailrace channel consists of a reinforced concrete downhill section and a horizontal riprap section, which connects smoothly with the downstream river.

12.7.3 Bank slope protection on both sides of outlet

The banks on both sides of the tailrace outlet will be protected according to the geological conditions and road layout.

The right side of the slope at the tailrace outlet is formed by excavation and is a rock slope. It is initially planned to adopt rockdowel and shotcrete support.

A permanent road to the tailrace tower will be arranged on the bank on the left side of the tailrace outlet. Most of the road foundation will be backfilled, and the side slope will be protected by riprap and steel cage, or by masonry and concrete retaining wall. The final protection plan will be designed later and verified by slope stability calculations.

12.8 Hydraulic

The hydraulic calculation of tailrace system used Flow 3d software. The calculation results show that the current tailrace tunnel meets the hydraulic requirements of tailrace system. Detail to refer to the document of Computational Fluid Dynamics (CFD) Analysis of Tailrace Tunnel | UT-I HEP (216 MW) | Sep 2022.

The head loss calculation of tailrace system is will be prepared and submitted in one separate document.

12.9 Structural analysis

The purpose of structural analysis is to analysis the stress condition of concrete structure in self-weight, external water pressure, internal water pressure, mechanical equipment, and other loads, and the reinforcement calculation.

The concrete structure of draft tunnel and tailrace tunnel will be analyzed by 2D model with thick wall members. The concrete structure of bifurcation tunnel and tailrace outlet will be analyzed by 3D model. The philosophy, load and combinations, Internal forces calculation method are same with the calculation of headrace tunnel.

Reinforcements calculation will be performed in accordance with requirements of EM 1110-2-2104 and ACI 318M, latest edition.

These structural analyses will be carried out gradually along with the design process.

12.10 Stability and foundation stress of outlet

The tail water outlet is located in the rock slope of the left bank, and the foundation elevation (EL.908.5m) is higher than the elevation (approximately EL.905m) of the river. There is a possibility of the outlet structure sliding to the river, so the anti-sliding stability calculation should be carried out. According to the geological conditions uncovered by excavation, the foundation of the outlet structure is mainly schist with strong weathering, so the foundation stress should be calculated, but there is no need for settlement analysis.

2D plane method will be adopted for calculation. The typical section along the axis of the cave will be selected as the basic section for calculation of foundation stress and anti-sliding stability. The

parameters of foundation rock mass will be based on the parameters of geological rock mass revealed on site.

12.11 Grouting

For draft tunnel and tailrace tunnel, consolidation grouting is designed to consolidate disturbed and fractured rock zone with poor geological condition, mainly namely class IV and class V, finally determined with exposed geological condition and the pressure test after excavation. And backfill grouting is designed to fill the void at the top of the cross section in whole concrete lining section of the tailrace tunnel.

For tailrace outlet, consolidation grouting should be carried out on the foundation to improve the sliding resistance and bearing capacity of the foundation.